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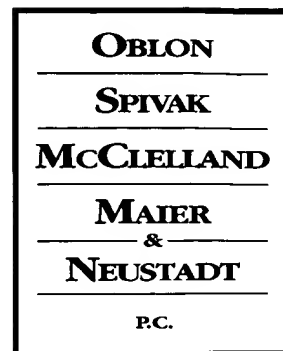
RE: Application Serial No.: 09/851,387
    Applicants: Mitsuhiro NADA
    Filing Date: May 9, 2001
    For: METHOD OF ESTIMATING TEMPERATURE AND
          DEVICE FOR THE EFFECTING SAME
    Group Art Unit: 2859
    Examiner: Verbitsky, G.

SIR:

    Attached hereto for filing are the following papers:

Certified English Translation of Japanese Application No. 2000-136001

    Our check in the amount of   is attached covering any required fees. In the event any variance exists between the amount enclosed and the Patent Office charges for filing the above-noted documents, including any fees required under 37 C.F.R 1.136 for any necessary Extension of Time to make the filing of the attached documents timely, please charge or credit the difference to our Deposit Account No. 15-0030. Further, if these papers are not considered timely filed, then a petition is hereby made under 37 C.F.R. 1.136 for the necessary extension of time. A duplicate copy of this sheet is enclosed.

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DECLARATION

TC 2800 MAIL ROOM

I, Yoshiko Kato, of c/o Toyota Techno Service Corp., 2-88, Hoei-cho, Toyota, Aichi, 470-1201 Japan, solemnly and sincerely declare:

That I have thorough knowledge of Japanese and English languages; and

That the attached pages contain a correct translation into English of the following Japanese patent application:

APPLICATION NUMBER	DATE OF APPLICATION
2000-136001	May 9, 1999

I hereby declare that all statements made herein of my own knowledge are true, and that all statements made on information and belief are believed to be true; and further, that these statements are made with the knowledge that willful false statements and the like so made, are punishable by fine or imprisonment, or both, under Section 1001, Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 16th day of May, 2003.

Yoshiko Kato

Yoshiko Kato

[NAME OF THE DOCUMENT]   APPLICATION FOR PATENT

[SERIAL NUMBER]   PA14D368

[DATE OF FILING]   MAY 9, 1999

[ADDRESSEE]   Mr. Takahiko Kondo, Commissioner of Patent Office

5   [INT. CL.]   G01K 7/00

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10   [LIST OF ATTACHED DOCUMENTS]

    [NAME OF THE DOCUMENT]   Specification   1

    [NAME OF THE DOCUMENT]   Drawing   1

    [NAME OF THE DOCUMENT]   Abstract   1

    [NUMBER OF THE GENERAL POWER OF ATTORNEY]   9708410

15   [NUMBER OF THE GENERAL POWER OF ATTORNEY]   9904031

[REQUIREMENT OF PROOF]   Required

[NAME OF THE DOCUMENT]   Specification

[TITLE OF THE INVENTION]   METHOD OF ESTIMATING
TEMPERATURE AND DEVICE FOR THE SAME

[CLAIMS]

5   [Claim 1]   A method of estimating a temperature, characterized by including the
steps of:

(a) specifying a first object which shows a relatively mild temperature change;

(b) specifying a second object which shows a relatively rapid temperature
change in response to presence or absence of its own heat generation due to

10   energization and is positioned in the vicinity of the first object for exchanging heat
with the first object, and in which a temperature settles down to a substantially equal
temperature as that of the first object in the absence of the heat generation;

(c) determining a temperature of one of the first and second objects; and

(d) estimating the temperature of the other of the first and second objects on

15   the basis of a temperature determined in the step (c) and a value that substantially
indicates the amount of the energization.

[Claim 2]   The method of estimating a temperature according to claim 1, wherein,
when the temperature of the first object is assumed as t1, the temperature of the

20   second object as t2, and a temperature increment quantity of the second object that is
related to the value that substantially indicates the amount of the energization as Δt,

a relation between the temperature increment quantity Δt and the value that
substantially indicates the amount of the energization is predetermined, and

the estimation in the step (d) is executed according to the following equation:

25     $T2 = T1 + \Delta t$.

[Claim 3]   The method of estimating a temperature according to claim 2, wherein
the second object is a power semiconductor,

the first object is a coolant for cooling the power semiconductor element, and

30   the step (d) includes a step of determining, from the relation between the
predetermined temperature increment quantity Δt and a value that substantially
indicates the amount of energization of the semiconductor element, the temperature

increment quantity Δt in accordance with the value that substantially indicates the amount of energization of the power semiconductor element.

[Claim 4]   The method of estimating a temperature according to claim 2, wherein the first object is a stator iron core of an electric motor,

the second object is a stator coil of the electric motor, and

the step (d) includes a step of determining, from the relation between the predetermined temperature increment quantity Δt and a value that substantially indicates the amount of energization of the electric motor, the temperature increment quantity Δt in accordance with the value that substantially indicates the amount of energization of the electric motor.

[Claim 5]   The method of estimating a temperature according to claim 4, wherein the step (c) includes a step of determining the temperature of the stator iron core on the basis of a temperature of a coolant for cooling the stator of the electric motor and the value that substantially indicates the amount of energization of the electric motor.

[Claim 6]   The method of estimating a temperature according to claim 1, wherein the second object is a stator iron core of an electric motor,

the first object is a coolant for cooling the stator of the electric motor, and

the step (d) includes a step of determining the temperature of the stator iron core on the basis of the temperature of the coolant and the value that substantially indicates the amount of energization of the electric motor.

[Claim 7]   The method of estimating a temperature according to claim 1, wherein the second object is a power semiconductor element,

the first object is a coolant for cooling the power semiconductor element,

the step (c) includes a step of measuring a temperature of the power semiconductor element with a temperature sensor installed on the power semiconductor element, and

the step (d) includes a step of determining a temperature of the coolant from the temperature change of the power semiconductor element in a state with no energization of the power semiconductor element.

[Claim 8]   A device for estimating, from a temperature of one of a first and second objects, the temperature of the other temperature, characterized in that

the first object has characteristics by showing a relatively mild temperature change,

the second object has characteristics by showing a relatively rapid temperature change in response to presence or absence of its own heat generation due to energization and is positioned in the vicinity of the first object for exchanging heat with the first object, and in which a temperature settles down to a substantially equal temperature as that of the first object in the absence of the heat generation, and

the device for estimating the temperature includes

a temperature determination portion for determining the temperature of one of the first and second objects; and

an estimation portion for estimating the temperature of the other of the first and second objects on the basis of the temperature determined by the temperature determination portion and a value that substantially indicates the amount of energization.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Field]

The invention relates to an art for estimating a temperature of a region in which no temperature sensor is installed.

[0002]

[Related Art]

In measuring temperatures, temperature sensors are commonly used. However, there is a case where it is desired to know the temperature of a region in which no temperature sensor can be installed directly. Moreover, the probability of the temperature sensor failure is likely to become higher as the number of the sensors increases. Accordingly there are some cases where decrease of the number of the temperature sensors is desired to the maximum extent. For such cases, conventionally, it has become the practice to measure a physical value other than the temperature and to estimate the temperature on the basis of a temperature dependence of the physical value. For example, Japanese Patent Laid-Open Publication No. 7-2344162 discloses an art where a forward current and a forward voltage of an

insulated gate type bipolar transistor (IGBT) are measured, and the temperate of the IGBT is estimated from the temperature dependence of the current-voltage characteristics thereof.

[0003]

Moreover, there are cases where, although the temperature sensor is installed, the temperature at the region is estimated by another means, to detect its malfunctioning. For example, Japanese Patent Laid-Open Publication No. 10-62266 discloses an art where, in order to detect malfunctioning of a thermistor for measuring a coil temperature of a motor, the coil temperature is estimated by another means. In this art, a resistance of the coil is obtained from the inductance and the current value of the coil, and the coil temperature is estimated from the temperature dependence of the resistance.

[0004]

[Problem to be Solved by the Invention]

In the conventional temperature estimation art described above, a specified physical characteristic concerning a region whose temperature is to be estimated is measured and then the temperature is estimated on the basis of the temperature dependence of the physical characteristic. For such a physical characteristic, one that shows a distinct temperature dependence is used.

[0005]

However, depending on the kind of the region to be estimated, there may be a case where a physical characteristic showing a distinct temperature dependence cannot be measured. Or there may be a case where, although the measurement of such a physical characteristic is feasible, its measurement is not desired because of the need to reduce the number of sensors. Due to various circumstances such as those, there is desired an art whereby the temperature can be estimated by means other than a method of directly using the temperature dependence of a physical characteristic of the region whose temperature is to be estimated.

[0006]

The invention has been made in order to solve the aforementioned conventional problems. It is an object of the invention to provide an art whereby the temperature can be estimated by means other than a method of directly using the temperature dependence of a physical characteristic of the region whose temperature is to be estimated.

[0007]

[Means for Solving the Problem and Effects]

In order to accomplish the aforementioned object, a method of estimating a temperature according to the invention includes steps of (a) specifying a first object that shows a relatively mild temperature change; (b) specifying a second object that shows a relatively rapid temperature change in response to the presence or absence of its own heat generation caused by energization, and which is positioned in the vicinity of the first object for exchanging heat with the first object, and in which a temperature settles down to a substantially equal temperature to that of the first object in the absence of heat generation; (c) determining the temperature of one of the first and second objects; and (d) estimating the temperature of the other of the first and second objects on the basis of the temperature determined in step (c) and a value that substantially indicates the amount of the energization. Incidentally, the determination of the temperature of the one object at step (c) may be done with a temperature sensor or by another estimation method.

[0008]

According to the aforementioned configuration, since the temperature of the other of the first and second objects is estimated on the basis of the temperature of the one object determined by some means, and the value that substantially indicates the amount of energization causing the heat generation of the second object, the temperature can be estimated by other means than methods of directly using the temperature dependence of a physical characteristic related to these objects.

[0009]

Incidentally, when the temperature of the first object is assumed as T1, the temperature of the second object as T2, and the temperature increment quantity of the second object that is related to the value that substantially indicates the amount of the energization as ΔT, a relation between the temperature increment quantity ΔT and the value that substantially indicates the amount of the energization is predetermined, and the estimation in step (d) is executed according to the following equation:

$$T2 = T1 + \Delta T.$$

[0010]

Accordingly, it is possible to determine the temperature increment quantity ΔT from the value that substantially indicates the amount of energization and to easily estimate the temperature of either of the first or second object by using this.

[0011]

Various combinations of the first and second objects are conceivable.

[0012]

For example, the second object may be a power semiconductor, and the first object may be a coolant for cooling the power semiconductor element. In this case, step (d) includes a step of determining the temperature increment quantity ΔT in accordance with a value that substantially indicates the amount of energization of the power semiconductor element from the relation between the predetermined temperature increment quantity ΔT and the value that substantially indicates the amount of energization of the semiconductor element.

[0013]

Normally, the power semiconductor element has a very small heat capacity and shows a rapid temperature change. Therefore, it is possible to easily estimate the temperature of one of the power semiconductor element and the coolant from the value that substantially indicates the amount of energization of the power semiconductor element and the coolant temperature.

[0014]

Or, the first object may be a stator iron core of an electric motor, and the second object may be a stator coil of the electric motor. In this case, step (d) includes a step of determining the temperature increment quantity ΔT in accordance with a value that substantially indicates the amount of energization of the electric motor from the relation between the predetermined temperature increment quantity ΔT and the value that substantially indicates the amount of energization of the electric motor.

[0015]

In this configuration, it is possible that the temperature of one of the stator iron core and the stator coil, and the value that substantially indicates the amount of energization of the motor, are used to estimate the temperature of the other.

[0016]

In this configuration, step (c) may include a step of determining the temperature of the stator iron core on the basis of the temperature of a coolant for cooling the stator of the electric motor and the value that substantially indicates the amount of energization of the electric motor.

[0017]

In this configuration, the temperature of the stator iron core can be determined from the coolant temperature, and further the temperature of the stator coil can be estimated from this.

[0018]

In another configuration, the second object may be a stator iron core of an electric motor, and the first object is a coolant for cooling the stator of the electric motor. Step (d) may include a step of determining the temperature of the stator iron core on the basis of the coolant temperature and a value that substantially indicates the amount of energization of the electric motor.

[0019]

In this configuration, it is possible that the temperature of either of the stator iron core or the coolant and the value that substantially indicates the amount of energization of the motor may be used to estimate the temperature of the other.

[0020]

Or, the second object may be a power semiconductor element, and the first object may be a coolant for cooling the power semiconductor element. In this case, step (c) may include a step of measuring the temperature of the power semiconductor element with a temperature sensor installed on the power semiconductor element, and step (d) may include a step of determining the temperature of the coolant from the temperature change of the power semiconductor element in a state where the power semiconductor element is not energized.

[0021]

In the state where there is no energization in the power semiconductor element, the temperature of the power semiconductor element rapidly settles down to a temperature substantially equal to the coolant temperature. Therefore, the coolant temperature can be determined from the temperature change of the power semiconductor element in the state without energization.

[0022]

Note that the invention can be realized in a variety of forms; for example, it is possible to realize it in a form such as a method and a device for estimating the temperature; a vehicle equipped with the device; a computer program whereby the method or a function of the device is achieved; a recording medium that records the computer program; data signals including the computer program that are realized in a carrier wave, etc.

[0023]

[Embodiments of the Invention]

Next, an embodiment of the invention will be described in the following order.

A.   General configuration of a hybrid vehicle

B.   Basic operation of hybrid vehicle

C.   Temperature estimation of the power transistor

D.   Temperature estimation of the first motor MG1

E.   Temperature estimation of the second motor MG2

F.   Temperature estimation of the cooling water (part 1)

G.   Temperature estimation of the cooling water (part 2)

I.   Modified examples

[0024]

A.   General configuration of a hybrid vehicle

FIG. 1 is an explanatory drawing showing a general configuration of a hybrid vehicle as one embodiment of the invention. This hybrid vehicle is equipped with three prime movers consisting of an engine 150 and two motors/generators MG1, MG2. Here, a "motor/generator" means an electronic motor that can function as a motor and also as a generator. Note that hereinafter each of the engine 150 and the motors/generators MG1, MG2 will be referred to simply as a "motor" for simplicity. The vehicle is controlled by a control system 200.

[0025]

The control system 200 has a main ECU 210, a brake ECU 220, a battery ECU 230, and an engine ECU 240. Each ECU includes a plurality of circuit elements, such as a micro computer, an input interface, and an output interface arranged on a single circuit board as one unit. The main ECU 210 has a motor control part 260 and a master control part 270. The master control part 270 has a function of determining a control quantity such as distribution of the output of the three prime movers 150, MG1, and MG2.

[0026]

The engine 150 is a normal gasoline engine which rotates a crankshaft 156. Operation of the engine 150 is controlled by the engine ECU 240. The engine ECU 240 executes control of fuel injection quantity of the engine 150 and others in accordance with a command from the master control part 270.

[0027]

Each of the motors MG1, MG2 is configured as a synchronous motor including rotors 132, 142 with a plurality of permanent magnets around their peripheral face, and a stator 133, 143 around which three phase coils 131, 141 for forming a rotational magnetic field are wound. The stators 133, 143 are fixed to a

5   case 119. Each of the three-phase coils 131, 141 that is wound around each of the stators 133, 143 of each of the motors MG1, MG2 is connected to a second battery 194 via each of driving circuits 191, 192. Each of the driving circuits 191, 192 is a transistor inverter provided with a pair of transistors, each pair being a switching element for each phase. The driving circuits 191, 192 are controlled by the motor

10   control part 260. When the transistors of the driving circuit 191, 192 are switched on by a control signal from the motor control part 260, a current flows between the battery 194 and the motors MG1, MG2. The motors MG1, MG2 can operate as electric motors that rotate for driving operation while receiving electric power from the battery 194 (hereinafter this operation state will be referred to as "power running")

15   and can also function as the electric generators that generate electromotive forces at both ends of the three-phase coils 131, 141 to charge the battery 194 when the rotors 132, 142 are made to rotate by an external force (hereinafter this operation state being referred to "regenerative running").

[0028]

20   Rotation axes of the engine 150 and the motors MG1, MG2 are mechanically linked to one another via a planetary gear 120. The planetary gear 120 is composed of a sun gear 121, a ring gear 122, and a planetary carrier 124 with a planetary pinion gear 123. In the hybrid vehicle of this embodiment, the crankshaft 156 of the engine 150 is linked to a planetary carrier axis 127 via a damper 130. The damper 130 is

25   provided to absorb twist vibrations occurring in the crankshaft 156. The rotor 132 of the motor MG1 is linked to a sun gear axis 125. The rotor 142 of the motor MG2 is linked to a ring gear axis 126. Rotation of the ring gear 122 is transmitted to an axle 112 and wheels 116R, 116L via a chain belt 129 and a differential gear 114.

[0029]

30   The control system 200 uses various sensors to achieve the control of the entire vehicle. Examples of the sensors include an accelerator sensor 165 for detecting the amount of depression of an accelerator pedal by the driver, a shift position sensor 167 for detecting a position of a gear lever, a brake sensor 163 for detecting a depressing pressure on a brake pedal, a battery sensor 196 detects a state of charge of

the battery 194, a revolution speed sensor 144 for measuring the revolution speed (the number of revolutions per unit time) of the motor MG2, etc. Since the ring gear axis 126 and the axle 112 are mechanically linked with the chain belt 129, a ratio of the revolution speeds of the ring gear 126 with respect to the axle 112 is constant.

5   Accordingly, with the revolution speed sensor 144 installed on the ring gear axis 126, not only the revolution speed of the motor MG2 but also the revolution speed of the axle 112 can be detected.

[0030]

FIG. 2 is an explanatory drawing showing an internal configuration of the
10   driving circuits 191, 192. Each of the driving circuits 191, 192 is a three-phase transistor inverter composed of six power transistors Tr1-Tr6, Tr11-Tr16, respectively. For the transistors Tr1-Tr6 and Tr11-Tr16, for example, various power semiconductor elements such as an IGBT can be used. The six transistors Tr1-Tr6 in the first driving circuit 191 have a configuration that they are arranged in such a way
15   that three sets of transistors, each of which consists of two transistors connected in series, are connected in parallel to power supply lines L1, L2. To each joint point of the three sets of the paired transistor is connected a coil part of the three-phase coil of the first motor MG1. The motor control part 260 (FIG. 1) forms pseudo sinusoidal waves from currents flowing through respective coil parts of the three-phase coil 134
20   by executing a PWM control of ratios of turn-on times of the transistors Tr1-Tr6. The second driving circuit 192 is configured in the same way as the first driving circuit 191.

[0031]

Note that two current sensors 197u, 197v for detecting currents Iu1, Iv1 are
25   installed in wires of a U phase and a V phase of three phase output wiring of the first driving circuit 191. Similarly, two current sensors 198u, 198v for detecting currents Iu2, Iv2 are installed in wires of a U phase and a V phase of three phase output wiring of the second driving circuit 192. Measured values of these currents are inputted to the motor control part 260 (FIG. 1). Incidentally, since the sum of the current values
30   of the three phases is zero, a current of the W phase is determined from the currents of the U phase and the V phase.

[0032]

B. Basic operation of the hybrid vehicle

To explain a basic operation of the hybrid vehicle, first, operation of the planetary gear 120 will be described below. The planetary gear 120 has a characteristic that when revolution speeds of the two of the three rotation axes are determined, the revolution speed of the other rotation axis is also determined. A relation of the revolution speeds of the rotation axes is as shown in the following equation (1).

[0033]

$$Nc = Ns \times \rho/(1+\rho) + Nr \times 1/(1+\rho) \ldots \quad (1)$$

[0034]

Where, Nc is a revolution speed of the planetary career axis 127, Ns is the revolution speed of the sun gear axis 125, and Nr is the revolution speed of the ring gear axis 126. Moreover, ρ is a gear ratio of the sun gear 121 and the ring gear 122, as expressed in the following equation.

[0035]

ρ=[number of teeth of the sun gear 121]/[number of teeth of the ring gear 122]

[0036]

Further, each torque of the three rotation axes has a certain relation given by the following equations (2), (3), regardless of the revolution speeds.

[0037]

$$Ts = Tc \times \rho/(1+\rho) \ldots (2)$$

$$Tr = Tc \times \rho/(1+\rho) = Ts/\rho \ldots (3)$$

[0038]

Where, Tc is a torque of the planetary carrier axis 127, Ts is a torque of the sun gear axis 125, and Tr is a torque of the ring gear axis 126.

[0039]

By virtue of a function of the planetary gear 120 like this, the hybrid vehicle of this embodiment can travel in various states. For example, in a comparatively low speed state when the hybrid vehicle starts travelling, the motor MG2 is made to perform power running while the engine 150 is being stopped, whereby power is transmitted to the axle 112 to propel the vehicle. Similarly, there may be a case where the vehicle is also made to travel while the engine 150 is in an idle state.

[0040]

When the hybrid vehicle reaches a predetermined speed after starting the travelling, the control system 200 puts the engine 150 in the motoring state with a

torque outputted from the motor MG1 for power running and makes it start. At this time, a reaction force torque of the motor MG1 is also outputted to the ring gear 122 via the planetary gear 120.

[0041]

When the engine 150 is operated and the planetary carrier axis 127 is made to rotate, the sun gear axis 125 and the ring gear axis 126 rotate under a condition that satisfies the foregoing equations (1) to (3). The power from the rotation of the ring gear axis 126 is transmitted, as it is, to the wheels 116R, 116L. The power from the rotation of the sun gear axis 125 can be recovered regeneratively by the first motor MG1 as electric power. On the other hand, if the second motor MG2 is made to perform power running, the power can be outputted to the wheels 116R, 116L via the ring gear axis 126.

[0042]

In a steady state operation, the output of the engine 150 is set to a value substantially equal to required power of the axle 112 (that is, [revolution speed of the axle 112] x [torque]). At this time, a portion of the output of the engine 150 is transmitted directly to the axle 112 via the ring gear axis 126, and the remaining output is recovered regeneratively by the first motor MG1 as electric power. The electric power so recovered is used to generate a torque with which the second motor MG2 makes the ring gear axis 126 rotate. As a result, the axle 112 can be driven at a desired revolution speed and with a desired torque.

[0043]

In the case where the torque to be transmitted to the axle 112 is insufficient, the second motor MG2 assists the torque. For electric power required for this assisting, the electric power that is recovered regeneratively by the first motor MG1 and the electric power that has been saved in the battery 149 are used. Thus, the control system 200 controls the operation of the two motors MG1, MG2 in response to the required power that is to be outputted from the axle 112.

[0044]

The hybrid vehicle of this embodiment can move in reverse while the engine 150 is being operated. When the engine 150 is operated, the planetary career axis 127 rotates in the same direction as that when the vehicle moves forward. At this time, if the sun gear axis 125 is made to rotate at a higher revolution speed than the revolution speed of the planetary carrier axis 127 by controlling the first motor MG1, the ring

gear axis 126 rotates in a backward direction, as is apparent from the foregoing equation (1). The control system 200 can make the hybrid vehicle move backward by controlling the output torque of the second motor MG2 while the second motor MG2 is made to be rotating in a backward direction.

[0045]

The planetary gear 120 can make the planetary carrier 124 and the sun gear 121 rotate while the ring gear 122 is stopped. Therefore, even when the vehicle is stopped, the engine 150 can be operated. For example, when a remaining capacity of the battery 194 decreases, the battery 194 can be charged by operating the engine 150 and also making the first motor MG1 perform regenerative operation. If the first motor MG1 is made to perform power running when the vehicle is stopped, the engine 150 can be put into the motoring state by its torque and be started.

[0046]

C. Temperature estimation of power transistors

FIG. 3 is an explanatory drawing showing a configuration of a cooling system for cooling power transistors of the driving circuits 191, 192. Twelve transistors 300 that constitute the driving circuits 191, 192 (Tr1-Tr6 and Tr11-Tr16 of FIG. 2) are soldered on a substrate 302. However, in FIG. 3, only one transistor is drawn for convenience for illustration. The substrate 302 is fixed on a cooling plate 306 made of aluminum by filler 304. This filler 304 is for increasing thermal conductivity between the substrate 302 and the cooling plate 306. A space above the transistor 300 is covered with a lid 308 made of aluminum. Moreover, a cooling passage 310 is formed inside the cooling plate 306 just below the transistor 300.

[0047]

Cooling water CLW for cooling the transistor 300 passes through the cooling passage 310 inside the cooling plate 306, then is pressurized by a pump 402 and cooled by a radiator 404, and returns to the cooling passage 310 again via a circulating passage 406. In a channel in front of the cooling plate 306 there is installed a temperature sensor 408 for measuring temperature of the cooling water CLW. Note that the radiator 404 is provided independently of a radiator for the engine.

[0048]

All of the substrate 302, the filler 304, and the cooling plate 306 are made of materials having good thermal conductivity. Therefore, the heat generated by the transistor 300 is rapidly conducted to the cooling water CLW via these members.

[0049]

Incidentally, the first motor MG1 is mainly used as a generator as described above, while the second motor MG2 is used mainly as a motor. As a result, normally the second motor MG2 has a larger current value. Moreover, since the heat generation becomes larger as the current value of a transistor becomes larger in general, the transistors Tr11-Tr16 (FIG. 2) for the second motor MG2 show a tendency of reaching a higher temperature than the transistors Tr1-Tr6 for the first motor MG1. Accordingly, in this embodiment, the V-phase transistors Tr13, Tr14 which are arranged in the center among the six transistors with a tendency of reaching the highest temperature, are chosen as the objects whose temperature are to be estimated.

[0050]

FIG. 4 is a graph showing one example of changes of the temperatures of the transistor and of the cooling water. When the transistor 300 is not operated, the transistor 300 does not generate the heat, and consequently the transistor temperature Ttr and the temperature of the water Tw are kept constant and kept at a substantially equal temperature. Moreover, the temperature of the airflow Tair that cools the radiator 404 is kept at a constant value slightly lower than these.

[0051]

When the transistor 300 is briefly turned on at time t1, the transistor temperature Ttr increases slightly due to the heat generation. However, since the heat capacity of the transistor 300 is much smaller than the heat capacities of the cooling plate 306 and the like, and the heat is rapidly conducted to the cooling water CLW, the transistor temperature Ttr immediately settles down rapidly to substantially the same value as the cooling water temperature Tw.

[0052]

From time t2 to time t3, the transistor 300 is continuously turned on at a constant output. In this case, since the calorific value is large, the transistor temperature Ttr gradually rises and, in accordance therewith, cooling water temperature Tw also rises. Then, when the operation of the transistor 300 stops at time t3, the transistor temperature Ttr settles down rapidly (in a few or few tens of

seconds) to the same temperature as the cooling water temperature Tw. Incidentally, it is assumed that the airflow temperature Tair is constant.

[0053]

As described above, the transistor temperature Ttr rises higher than the cooling water temperature Tw during the operation of the transistor 300 and when the operation is stopped, it drops down to substantially the same temperature as the cooling water temperature Tw. Moreover, during the operation of the transistor 30, a difference ΔTtr/w between the transistor temperature Ttr and the cooling water temperature Tw is kept almost constant.

[0054]

The transistor temperature Ttr(i) at an arbitrary time i can be expressed by the following equation (4).

[0055]

Ttr(i) = Ttr(i-1)+K11 · PLtr(i)-K12[Tt(i-1)-Tw(i-1)] ... (4)

[0056]

Where, PLtr(i) is the calorific value of all the transistors (power loss) from time (i-1) to time i, and K11 and K12 are predetermined coefficients, respectively.

[0057]

The first term on the right side of the equation (4) is the transistor temperature at time (i-1). The second term on the right side represents the temperature increment quantity due to the heat generation of the transistors and the third term on the right side represents a temperature decrement quantity due to thermal conduction thereof to the cooling water CLW. Incidentally, the second and third terms on the right side are the amounts of temperature change per unit time. Here, "unit time" means a period of time from time (i-1) to time i.

[0058]

Strictly speaking, other elements such as a temperature decrease due to thermal radiation from the transistor 300 and a temperature decrease due to the thermal conduction to the substrate 302 should be considered in the foregoing equation (4). However, it turns out that contributions from these other components are sufficiently small and can be disregarded.

[0059]

Incidentally, it turns out that the second term on the right side of the foregoing equation (4) is kept at a constant value so long as the transistor is operated at a

constant output. In other words, the second term on the right side is given as a function of the output of the transistor. Moreover, as can be understood from the example of FIG. 4, as long as the output of the transistor is constant, the difference $\Delta T tr/w$ between the transistor temperature Ttr and the cooling water temperature Tw

5 is almost constant. This means that the third term on the right side of the equation (4) is an almost constant value. Therefore, the third term on the right side is also given as a function of the output of the transistor. That is, the second term and the third term on the right side are both found to be functions of the output of the transistor. Considering these facts, the foregoing equation (4) can be rewritten as the following

10 equation (5).

[0060]

$$Ttr(i) = Ttr(i-1) + \Delta Ttr(Ptr) \ldots (5)$$

[0061]

Where, $\Delta Ttr(Ptr)$ indicates an amount of change of the transistor temperature

15 per unit time when the output of the transistor is Ptr. The amount of change of the transistor temperature $\Delta Ttr(Ptr)$ corresponds to an increasing rate of temperature when the transistor temperature Ttr increases almost linearly at a period after time t2 in FIG. 4.

[0062]

20 Incidentally, the transistor temperature Ttr(i-1) at time (i-1) is expressed by the sum of the cooling water temperature Tw(i-1) and the transistor/cooling water temperature difference $\Delta Ttr/w$. Therefore, the foregoing equation (5) type can be rewritten as the following equation (6).

[0063]

25 $$Ttr(i) = Tw(i-1) + \Delta Ttr/W(Ptr) + \Delta Ttr(Ptr) \ldots (6)$$

[0064]

Combining the second term and the third term on the right side into one term, the following equation (7) is obtained.

[0065]

30 $$Ttr(i) = Tw(i-1) + \Delta T(Ptr) \ldots (7)$$

where, $\Delta Ttr/w(Ptr) + \Delta T(Ptr) = \Delta Ttr(Ptr)$.

[0066]

That is, the transistor temperature Ttr(i) at time i when the output of the transistor is Ptr is given by summation of the cooling water temperature Tw(i-1) at

time (i-1) and the temperature deviation. $\Delta T(Ptr)$ that depends on the output of the transistor.

[0067]

Here, the third term on the right side of the equation (6) is the increasing rate of the transistor temperature and is substantially equal to an increasing rate of the cooling water temperature, which can be understood from FIG. 4. Therefore, the sum of the first term and the third term on the right side of equation (6) is substantially equal to the water temperature $Tw(i)$ at time i. Then, it is also possible to rewrite the foregoing equation (6) to the following equation (8).

[0068]

$Ttr(i) = Tw(i)+\Delta T'(Ptr) \ldots (8)$

where,

$\Delta T'(Ptr) = \Delta Ttr/w(Ptr)$

[0069]

The cooling water temperatures $Tw(i-1)$, $Tw(i)$ are measured by the temperature sensor 408 (in FIG. 3) installed in the circulating passage 406. Moreover, the temperature deviations $\Delta T(Ptr)$, $\Delta T'(Ptr)$ are determined, for example, by a map for indicating a value of the temperature deviation in accordance with current values of the motors MG1, MG2 and a three-phase alternating current frequency. This map is made experimentally beforehand. Note that since the first motor MG1 is mainly used as the generator, the current value thereof is comparatively small, and hence the heat generation by the transistors for the first motor MG1 can be disregarded. Therefore, in this embodiment, the temperature deviations $\Delta T(Ptr)$, $\Delta T'(Ptr)$ are determined on the basis of the current values and the three-phase alternating current frequency of the second motor MG2 used mainly as the motor.

[0070]

FIG. 5 shows one example of the map of the temperature deviation $\Delta T(Ptr)$. In this map, the relation between the current value of the motor and the temperature deviation ΔT of the transistor is shown for different values of the three-phase alternating current frequency.

[0071]

Thus, the transistor temperature Ttr can easily be estimated as the sum of the measured value of the cooling water temperature Tw and the temperature deviation ΔT that depends on the output Ptr of the transistor. Therefore, the transistor

temperature can be estimated without directly using the temperature dependence of a physical characteristic of the transistor such as the temperature dependence of the current value of the transistor.

[0072]

The temperature deviations ΔT, $\Delta T'$ is not limited to the current value or the three-phase alternating current frequency, and it may be determined on the basis of another value that substantially indicates the mount of energization of the transistor. For example, the temperature deviations ΔT, $\Delta T'$ may be determined on the basis of a torque command value that is given to the motor control part 260 from the master control part 270 and a carrier frequency of a driving signal (frequency of a driving signal pulse in PWM control) that is given to the driving circuits 191, 192 from the motor control part 260.

[0073]

Incidentally, the calorific value of the transistor depends also on whether the current supplied to the motor is a sinusoidal wave or a rectangular wave. Therefore, different maps of the temperature deviations ΔT, $\Delta T'$ for each waveform may be prepared.

[0074]

D. Temperature estimation of the first motor MG1

FIG. 6 is an explanatory drawing showing the configuration of the cooling system for cooling the first motor MG1. The first motor MG1 has a rotor 320, a stator coil 322, and a stator iron core 324, and these are housed in a motor case 326. A periphery of the motor case 326 is enclosed with a jacket 328, and the passage of the cooling water CLW is formed therebetween.

[0075]

The configuration of the cooling system of FIG. 6 is substantially the same as the cooling system for the transistor shown in FIG. 3. Incidentally, the cooling system for the transistor and that for the motor may be constructed as a single system for common use, but here description will be made assuming that these are independent of each other.

[0076]

Factors of the heat generation in the first motor MG1 include copper loss (loss in the coil 322) and iron loss (loss in the iron core 324). Since the first motor MG1 is mainly used as the generator and the current density is comparatively small, the

copper loss is small and can be disregarded. Therefore, all that should be considered as the factor of heat generation in the first motor MG1 is the iron loss, and hence the temperature of the stator iron core 324a rises to the highest.

[0077]

FIG. 7 is a graph showing one example of changes of the iron core temperature and the cooling water temperature of the first motor MG1. When the motor MG1 is not being operated, there is no heat generation in the iron core, and hence the iron core temperature Tgf and the water temperature TW are kept constant and at substantially the same temperature.

[0078]

From time t11 to time t12, the motor MG1 is continuously operated at a constant output. At this time, the iron core temperature Tgf rises gradually and the cooling water temperature Tw also rises. Then, when the supply of the electric power to the motor MG1 is stopped at time t12, the iron core temperature Tgf slowly approaches the cooling water temperature Tw, and finally both temperatures settle down to substantially the same temperature.

[0079]

Thus, the iron core temperature Ttr of the first motor MG1 has a characteristic that when the MG1 is supplied with the electric power, it is higher than the cooling water temperature Tw, but once the supply of the electric power is stopped, it slowly settles down to substantially the same temperature as the cooling water temperature Tw.

[0080]

The iron core temperature Tgf(i) at an arbitrary time i can be expressed by the following equation (9).

[0081]

$$Tgf(i) = Tgf(i-1) + K21 \times PLgf(i) - K22[Tgf(i-1) - Tw(i-1)] \ldots (9)$$

[0082]

Where PLgf(i) is a calorific value of the iron core from time (i-1) to time i, and K21 and K22 are predetermined coefficients, respectively. The second term on the right side of the equation (9) represents the temperature increment quantity due to the heat generation and the third term on the right side represents the temperature decrement quantity due to cooling.

[0083]

As can be understood by comparing FIG. 7 and FIG. 4, the change of the iron core temperature is comparatively slow and the temperature deviation $\Delta Tgf/w$ between the iron core temperature Tgf and the cooling water temperature Tw also changes slowly with time. This is because the iron core 324 has a considerably large heat capacity.

[0084]

The iron core temperature Tgf of the first motor MG1 is determined by using the equation (9) as it is. Unknown numbers on the right side of the equation (9) are the water temperature Tw(i-1) and the calorific value of the iron core PLgf. The water temperature Tw(i-1) is measured by the temperature sensor 408 installed in the circulating passage 406. Moreover, the calorific value PLgf is determined from a map that has been made beforehand in accordance with a value that substantially indicates the output of the motor, such as the torque and the revolution speed of the motor. This map is similar to that of FIG. 5 described above and its illustration is omitted here.

[0085]

Incidentally, an initial value of the iron core temperature Tgf is determined by measuring the water temperature Tw in a state where the motor MG1 has not been supplied with electric power for a sufficiently long time and then adding a predetermined temperature deviation $\Delta T0w$ to this water temperature Tw. This temperature deviation $\Delta T0w$ is obtained experimentally beforehand for different levels of the water temperature Tw. Alternatively, it may be possible to store the water temperature Tw and the iron core temperature Tgf when the energization is stopped and to estimate the temperature deviation $\Delta T0w$ by using the equation (9) in accordance with an idle time of zero torque.

[0086]

As mentioned above, the iron core temperature Tgf of the first motor MG1 can be estimated on the basis of the cooling water temperature Tw and the calorific value PLgf(i) that depends on the output of the motor MG1 (or the amount of energization of the motor). The iron core temperature can be estimated without directly using the temperature dependence of a physical characteristic of the motor.

[0087]

E. Temperature estimation of the second motor MG2

FIG. 8 is an explanatory drawing showing a method of cooling the second motor MG2. The second motor MG2 has a rotor 340, a stator coil 342, and a stator iron core 344, and these are housed in a motor case 346. The motor case 326 is cooled by airflow. Incidentally, the iron core 344 is provided with a temperature sensor 350. Moreover, in front of the motor MG2 installed is a temperature sensor 352 for measuring the outside ambient temperature.

[0088]

The second motor MG2 is used mainly as a motor, and since the electric current density is comparatively large, the copper loss cannot be disregarded. Then, both the copper loss and the iron loss are considered as heating factors in the second motor MG2. Incidentally, it is in the stator coil 342 that the temperature rises highest.

[0089]

FIG. 9 is a graph showing an example of changes of the coil temperature Tmc and the iron core temperature Tmf of the second motor MG2. When the motor MG2 is not operated, there is no heat generation and hence temperatures Tmc, Tmf are kept constant and at substantially the same.

[0090]

When the motor MG2 is supplied with electric power at time t21, the coil temperature Tmc also increases slightly due to heat generation, and in accordance with this the iron core temperature Tmf also increases a little. However, since the heat capacity of the coil 342 is very small compared to the heat capacity of the iron core 344 and the thermal conductivity between the two members is high, the coil temperature Tmc settles down to substantially the same value as the iron core temperature Tmf in a comparatively short time.

[0091]

From time t22 to time t23, the motor MG2 is continuously operated at a constant output. At this time, the coil temperature Tmc and the iron core temperature Tmf rise gradually. Then, when the supply of the electric power to motor MG2 is stopped at time t23, the coil temperature Tmc approaches the iron core temperature Tmf in a comparatively short time. Further, the iron core temperature slowly approaches the outside ambient temperature Tair and finally settles down to substantially the same temperature as the outside ambient temperature Tair.

[0092]

In this way, the coil temperature Tmc of the second motor MG2 changes in a comparatively rapid manner, while the iron core temperature Tmf changes in a comparatively slow manner. Moreover, the coil temperature Tmc has a characteristic that when the motor MG1 is supplied with electric power, the coil temperature Tmc rises higher than the iron core temperature Tmf, but when the supply of the electric power is stopped, the coil temperature settles down to substantially the same temperature as the iron core temperature Tmf.

[0093]

The coil temperature Tmc(i) at an arbitrary time i can be expressed by the following equations (10).

[0094]

Tmc(i) = Tmc(i-1)+K31 · PLm(i)-K32[Tmc(i-1)-Tmf(i-1)] ... (10)

[0095]

Where, PLm(i) is the calorific value of the motor MG2 from time (i-1) to time i, and K31 and K32 are predetermined coefficients, respectively. Note that a proportion of the heat generated in the coil 342 of the heat generation by the motor MG2 is considered in the term of the calorific value of the motor, K31 · PLm(i). That is, the second term on the right side of the equation (10) represents the temperature increment quantity due to the heat generation of the coil 342. Moreover, the third term on the right side represents the temperature decrement quantity due to the thermal conduction from the coil 342 to the iron core 344.

[0096]

The relation between the coil temperature Tmc and the iron core temperature Tmf in FIG. 9 is similar to the relation between the transistor temperature Ttr and the cooling water temperature Tw shown in FIG. 4. Then, in this embodiment, as an equation that gives the coil temperature Tmc, the following equation (11) that is analogous to the foregoing equation (7) is used instead of the equation (10).

[0097]

Tmc(i) = Tmf(i-1)+ΔT(Pm) ... (11)

[0098]

Where, Pm is an output of the motor MG2. That is, the coil temperature Tmc(i) at time i when the motor MG2 is being operated at output Pm is given by the summation of the iron core temperature Tmf(i-1) at time (i-1) and the temperature deviation ΔT(Pm) in accordance with the output of the motor MG2.

[0099]

Note that it is also possible to use the following equation (12) that is analogous to the foregoing equation (8) instead of the equation (11).

[00100]

$$Tmc(i) = Tmf(i)+\Delta T'(Pm) \dots (12).$$

[00101]

The iron core temperatures $Tmf(i-1)$, $Tmf(i)$ are measured by the temperature sensor 350 (FIG. 8) installed in the iron core 344. Moreover, the temperature deviations $\Delta T(Pm)$, $\Delta T'(Pm)$ are determined from a map that indicates the temperature deviations, each of which corresponds to a value (or values) that substantially indicates the output of the motor, such as the torque and the revolution speed of the motor. This map is similar to FIG. 5 described above and its illustration is omitted here.

[00102]

Thus, if the iron core temperature Tmf can be measured, the iron core temperature Tmc can easily be estimated as the sum of the measured value of the iron core temperature and the temperature deviation ΔT that depends on the output of the motor MG2. Therefore, the coil temperature can be estimated without directly using the temperature dependence of a physical characteristic of the coil, like the temperature dependence of the coil resistance.

[00103]

Incidentally, if the iron core temperature Tm of the first term on the right side of the foregoing equation (11) or (12) cannot be measured, it is possible to estimate the iron core temperature Tmf from the outside ambient temperature $Tair$. At this time, the iron core temperature $Tmf(i)$ at an arbitrary time i can be expressed by the following equation (13).

[00104]

$$Tmf(i) = Tmf(i-1)+K41 \cdot PLm(i)-K42[Tm(i-1)-Tair(i-1)] \dots (13)$$

[00105]

Where K41 and K42 are predetermined coefficients, respectively. Note that the heat conducted from the coil 342 to the iron core 344 is considered in the term of the calorific value of the motor, $K41 \cdot PLm(i)$. The outside ambient temperature $Tair(i-1)$ included in the third term on the right side is measured by the temperature sensor 352 (FIG. 8) installed on the upstream side of the motor MG2. Incidentally,

the influence of the velocity of the cooling airflow on the cooling by the airflow can be disregarded and is not considered in the third term on the right side.

[00106]

The initial value of the iron core temperature Tmf in the foregoing equation (13) is determined by adding a predetermined temperature deviation ΔT0air to the outside ambient temperature Tair measured when the motor MG1 is not supplied with electric power for a sufficiently long period. This temperature deviation ΔT0air is obtained experimentally beforehand for each of various levels of the outside ambient temperature Tair.

[00107]

As mentioned above, the iron core temperature Tmf of the second motor MG2 can be estimated on the basis of the temperature Tair of the outside air that serves as a coolant and the calorific value PLm(i) that depends on the output of the motor MG2 (or the amount of energization of the motor). The iron core temperature can be estimated without directly using the temperature dependence of a physical characteristic of the motor.

[00108]

Further, by using the iron core temperature Tmf which is estimated in this method, the coil temperature Tmc can also be estimated with the foregoing equation (11) or (12).

[00109]

F. Temperature estimation of the cooling water (part 1)

FIG. 10 is an explanatory drawing showing another configuration of a cooling system for cooling the power transistors. A difference of this configuration from the configuration shown in FIG. 3 is the use of a temperature sensor 312 for measuring the temperature Ttr of the transistor 300 instead of the temperature sensor 408 for the cooling water. With such a configuration, the cooling water temperature Tw can be estimated from the measured value of the transistor temperature Ttr.

[00110]

The cooling water temperature Tw(i) at an arbitrary time i can be expressed by the following equations (14).

[00111]

$$Tw(i) = Tw(i-1)+K51[Ttr(i-1)-Tw(i-1)]-K52[Tw(i-1)-Tair(i-1)] \ldots (14)$$

[00112]

Where K51 and K52 are predetermined coefficients, respectively. The second term on the right side of the equation (14) represents the temperature increment quantity due to the thermal conduction from the transistor, and the third term on the right side represents the temperature decrement quantity due to the cooling with the radiator 404.

[00113]

When the cooling water temperature Tw is estimated by using this equation (14), normally the outside ambient temperature Tair is measured with the temperature sensor. However, it is also possible to estimate the cooling water temperature Tw by the equation (14) using the outside ambient temperature Tair estimated by other methods, as will be described later.

[00114]

Incidentally, instead of the above-described equation (14), it is possible to use the following equation (15) that is obtained by modifying the above-described equation (8).

[00115]

$$Tw(i) = Ttr(i) - \Delta T'(Ptr) \ldots (15)$$

[00116]

Where, $\Delta T'(Ptr)$ is the temperature deviation that depends on the output Ptr of the transistor. That is, the cooling water temperature Tw(i) can be estimated as a difference of the measured value of the transistor temperature Ttr and the temperature deviation ΔT that depends on the output Ptr of the transistor.

[00117]

When the output of the transistor is zero, the second term on the right side of the equation (15) is also zero. Therefore, when the operating state and the stopped state of the transistor are alternately repeated, the transistor temperature Ttr and the cooling water temperature Tw show changes, for example, as shown in FIG. 11. That is, the water temperature Ttr when the output of the transistor is zero is substantially equal to the cooling water temperature Tw.

[00118]

Considering such a phenomenon, the cooling water temperature Tw when the output of the transistor is zero can be estimated by using the following equation (16):

$$Tw(i) = Ttr(i) - \delta \ldots (16)$$

[00119]

Where, Ttr(i) is a measured value of the transistor temperature and δ denotes a predetermined temperature difference. This temperature difference δ is a value to be determined experimentally, but may be assumed as δ = 0.

[00120]

In various methods of estimating a temperature, using the temperature of one of the first object (e.g., the cooling water or the stator iron core) that shows a comparatively small temperature change and the second object (e.g., the transistor or the stator coil) that shows a comparatively rapid temperature change, the temperature of the other is estimated. As the second object, selected is an object having a property such that it generates heat arising from its energization and whose temperature settles down to a temperature substantially equal to that of the first object when the heat generation is absent. Moreover, the first and second objects are positioned in mutual vicinity and in conductive heat exchange. Here, a relation that "the first and second object are positioned in mutual vicinity" does not require that both members should be in direct contact with each other, but only requires that both members should be at such positions that substantial heat exchange occurs.

[00121]

G. Temperature estimation of cooling water (part 2)

FIG. 12 is an explanatory drawing showing the configuration of a common cooling system for cooling the power transistors and the first motor MG1. This cooling system is different from the system shown in FIG. 10 only in the respect that a cooling passage for the first motor MG1 is inserted between the driving circuits 191, 192 and the pump 402 and the configuration is otherwise the same as the system shown in FIG. 10. Also with such a configuration, the cooling water temperature Tw can be estimated from the measured value of the transistor temperature Ttr.

[00122]

The cooling water temperature Tw(i) at an arbitrary time i can be expressed by the following equation (17).

[00123]

$$Tw(i) = Tw(i-1) + K61 \cdot PLg(i) + K62 \cdot PLm(i) - K63[Tw(i-1) - Tair(i-1)] \ldots (17)$$

[00124]

Where K61, K62, and K63 are predetermined coefficients, respectively. A second term on the right side in the equation (17) represents the sum of the temperature increment quantity due to the iron loss of the first motor MG1 and the

temperature increment quantity due to the heat generation of the transistor 300 for

driving the first motor MG1. A third term on the right side represents the temperature

increment quantity due to the heat generation of the transistor 300 for driving the

second motor MG2. Moreover, a fourth term on the right side represents the

5   temperature decrement quantity due to cooling.

[00125]

The second term on the right side of the equation (17) is determined from a

map that has been made beforehand in such a way that each piece of data therein

corresponds to the value(s) that substantially indicates the amount of energization of

10   the first motor MG1 (the current value and the three-phase alternating current

frequency, or the torque and the carrier frequency). Moreover, the third term on the

right side is determined similarly from a map that has been made beforehand in such a

way that each piece of data therein corresponds to the value that substantially

indicates the amount of energization of the second motor MG2. Note that parameters

15   in these maps may be partly simplified. For example, since the carrier frequency of

the torque and the carrier frequency have a comparatively small influence, a map in

which only the torque is chosen for a parameter may be used instead.

[00126]

If the outside ambient temperature Tair of the fourth term on the right side of

20   the equation (17) is measured by the temperature sensor, the water temperature Tw at

an arbitrary time i can be estimated. However, in this embodiment, both the cooling

water temperature Tw and the outside ambient temperature Tw are estimated using

the temperature sensor 312 installed on the transistor 300 in the following manner,

without using the temperature sensor for the outside ambient temperature Tair.

25   [00127]

FIG. 13 is a flowchart representing the procedure by which the cooling water

temperature and the outside ambient temperature are estimated. This processing is

achieved by a CPU, not shown, that is in the master control part 270 executing a

predetermined program.

30   [00128]

At step S1, an initial value is set for the outside ambient temperature Tair. For

this initial value, an arbitrary temperature (e.g., 10°C) is used. At step S2, the

transistor temperature Ttr when the each torque of the two motors MG1, MG2 is zero

is measured with the temperature sensor 312.

[00129]

At step S3, the water temperature Tw is estimated from an envelope curve of the transistor temperature Ttr when the torque is zero, as follows. When each torque of the two motors is zero, as shown in FIG. 11 described above, the transistor temperature Ttr settles down to almost the water temperature Tw. Therefore, the water temperature Tw at this time can be estimated by using the foregoing equation (16).

[00130]

At step S4, the change of the water temperature Tw' when each torque of the two motors is zero is estimated by using the initial value of the outside ambient temperature Tair. The change of the water temperature Tw' when each torque of the two motors is zero is given by the following equation (18) that is obtained by substituting zeros for the second and third terms on the right side of the foregoing equation (17).

[00131]

$$Tw'(i) = Tw'(i-1)-K63[Twi(i-1)-Tair(i-1)] \ldots (18)$$

[00132]

As can be understood from this equation, the cooling water CLW is cooled by the outside air, and its temperature decreases gradually as shown in the right end of FIG. 11. If the actual outside ambient temperature Tair agrees with the initial value being set at step S1, the water temperature Tw estimated by using the equation (16) is supposed to agree with the water temperature Tw' estimated by using the equation (18). Then, at step S5, the outside ambient temperature Tair is modified so that these two estimated values of the water temperatures Tw, Tw' agree with each other.

[00133]

At step S6, it is examined whether or not the modified outside ambient temperature Tair is in a predetermined range that is considered to be normal. For example, as a normal range of the outside ambient temperature Tair, a range of -40 to +60°C is set. On one hand, if the modified outside ambient temperature Tair is not within the normal range, the driver has a warning that there is malfunctioning at step S8. Incidentally, for causes of malfunctioning, there can be considered several causes such as the pump 402 of the cooling system and the temperature sensor 312 of the transistor 300.

[00134]

On the other hand, if the modified outside ambient temperature Tair is within the normal range, the routine proceeds to step S7, where, by using this modified outside ambient temperature Tair, the water temperature Tw at an arbitrary time can be estimated according to the equation (17).

[00135]

Incidentally, this modified outside ambient temperature may be used as the initial value in the next trip. Here, "trip" means one traveling operation of the vehicle (from key-on to key-off).

[00136]

When the outside ambient temperature Tair has been thus estimated, the water temperature Tw can be estimated by using the foregoing equation (17) even in the case where each torque of the two motors MG1, MG2 is not zero. Further, by using the foregoing equation (7) or (8), the transistor temperature Ttr can be inversely estimated from this water temperature Tw. If the transistor temperature thus inversely estimated is considerably different from the temperature measured by the temperature sensor 312, there is a possibility that the temperature sensor 312 is malfunctioning. That is, it is possible to detect whether or not the temperature sensor 312 is malfunctioning by using the estimated water temperature Tw.

[00137]

Incidentally, if the hybrid vehicle is provided with a temperature sensor for measuring the outside ambient temperature, the measured value of the temperature sensor can be used as the outside ambient temperature in the foregoing equation (17). Moreover, it is possible to detect whether or not the outside ambient temperature sensor or the cooling system is malfunctioning by knowing whether or not the this measured value of the outside ambient temperature agrees with an estimated value of the outside ambient temperature obtained at step S5 of FIG. 13.

[00138]

Generalizing the estimation of the cooling water temperature described here, it is possible that: first the temperature of the first object (the cooling water temperature) is estimated by using the temperature of the second object (transistor temperature or outside ambient temperature) measured by the temperature sensor; and then the temperature of the second object is inversely estimated on the basis of the temperature of the first object, the temperature increment component and the temperature decrement component in the second object. Then, it is possible to detect whether or

not the temperature sensor is malfunctioning by checking the difference between the temperature of the second object that was inversely estimated and the temperature measured by the temperature sensor.

[00139]

Incidentally, one of two causes of malfunctioning is the temperature sensor of the second object, and the other is at least one of the cooling systems for the first object and for the second object. Therefore, it is possible to detect that at least one of these two constituents is malfunctioning. Incidentally, a variety of temperature estimations described in the embodiments are achieved by a CPU that is in the master control part 270 (but not shown in the figures) executing a predetermined program for estimating a temperature. This computer program is stored in ROM that is in the master control part 270 (but not shown in the drawings). Therefore, the master control part 240 corresponds to the estimation part in the invention. Incidentally, the temperature determination part in the invention is realized with various temperature sensors. However, in the case where the temperature of a region in which no temperature sensor is installed is determined, the master control part 270 also functions as the temperature determination part.

[00140]

H. Modified examples

Note that the invention is not limited to the embodiments but can be put into practice in a variety of forms within a scope that does not deviate from its essential points; for example, a variant as in the following is possible.

[00141]

H1. Modified example 1

In the embodiments described above, the hybrid vehicle of the so-called mechanical distribution type where the power of the engine is distributed to both the axle and the first motor MG1 with the use of the planetary gear. However, the invention may be applied to the hybrid vehicle of the so-called electric distribution type where the power of the engine is distributed electrically with the use of the motor/generator, without using a planetary gear. The hybrid vehicle of the electric distribution type is disclosed by, for example, Japanese Patent Laid-open Publication No. H9-46965 applied by the present inventors. Accordingly its explanation will be omitted.

[00142]

Further, the invention can be applied to other vehicles than hybrid vehicles. Moreover, the invention can be applied to temperature estimation and detection of malfunctioning in a variety of machines and apparatuses other than vehicles.

5   [BRIEF DESCRIPTION OF THE DRAWINGS]

[FIG. 1]

FIG. 1 is an explanatory drawing showing a general configuration of a hybrid vehicle as a first embodiment of the invention.

[FIG. 2]

10   FIG. 2 is an explanatory drawing showing an inner structure of the driving circuits 191, 192.

[FIG. 3]

FIG. 3 is an explanatory drawing showing the configuration of a cooling system for cooling the transistor of the driving circuits 191, 192.

15   [FIG. 4]

FIG. 4 is a graph showing one example of changes of a transistor temperature and of a cooling water temperature.

[FIG. 5]

FIG. 5 is a graph showing one example of a map of a temperature deviation

20    $\Delta T(Ptr)$ to be used when the transistor temperature is obtained.

[FIG. 6]

FIG. 6 is an explanatory drawing showing the configuration of the cooling system for cooling the first motor MG1.

[FIG. 7]

25   FIG. 7 is a graph showing one example of changes of the iron core temperature of the first motor MG1 and of the cooling water temperature.

[FIG. 8]

FIG. 8 is an explanatory drawing showing the method of cooling the second motor MG2.

30   [FIG. 9]

FIG. 9 is a graph showing one example of changes of the coil temperature of the second motor MG2 and of the iron core temperature.

[FIG. 10]

FIG. 10 is an explanatory drawing showing another configuration of a cooling system for cooling the power transistors.

[FIG. 11]

FIG. 11 is a graph showing changes of the transistor temperature Ttr and the cooling water temperature TW when the transistor is subject to operating and stopped states that are repeated alternately.

[FIG. 12]

FIG. 12 is an explanatory drawing showing the configuration of a common cooling system for cooling the power transistor and the first motor.

[FIG. 13]

FIG. 13 is a flowchart representing the procedure by which the cooling water temperature and the outside ambient temperature are estimated.

[Description of the Reference Numerals]

112   AXLE

114   DIFFERNTIAL GEAR

116R, 116L   WHEEL

119   CASE

120   PLANETARY GEAR

121   SUN GEAR

122   RING GEAR

123   PLANETARY PINION GEAR

124   PLANETARY CARRIER

125   SUN GEAR AXIS

126   RING GEAR AXIS

127   PLANETARY CAREER AXIS

129   CHAIN BELT

130   DAMPER

131   THREE-PHASE COIL

132   ROTOR

133   STATOR

141   THREE-PHASE COIL

142   ROTOR

143   STATOR

5   144   REVOLUTION SPEED SENSOR (REVOLUTION ANGLE SENSOR)

149   BATTERY

150   ENGINE

156   CRANKSHAFT

163   BRAKE SENSOR

10   165   ACCELERATOR SENSOR

167   SHIFT POSITION SENSOR

191, 192   DRIVING CIRCUITS

194   BATTERY

196   BATTERY SENSOR

15   197u, 197v   CURRENT SENSOR

198u, 198v   CURRENT SENSOR

200   CONTROL SYSTEM

210   MAIN ECU

212   BI-DIRECTIONAL COMMUNICATION WIRING

20   214   BI-DIRECTIONAL COMMUNICATION WIRING

220   BRAKE ECU

230   BATTERY ECU

240   ENGINE ECU

260   MOTOR CONTROL PART

25   270   MASTER CONTROL PART

300   TRANSISTOR

302   SUBSTRATE

304   FILLER

306	COOLING PLATE
308	LID
310	COOLING PASSAGE
312	TEMPERATURE SENSOR
320	ROTOR
322	STATOR COIL
324	STATOR IRON CORE
326	MOTOR CASE
328	JACKET
340	ROTOR
342	STATOR COIL
344	STATOR IRON CORE
346	MOTOR CASE
350	TEMPERATURE SENSOR
352	TEMPERATURE SENSOR
402	PUMP
404	RADIATOR
406	CIRCULATING PASSAGE
408	TEMPERATURE SENSOR

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[NAME OF THE DOCUMENT]   Abstract of the disclosure

[ABSTRACT]

[TASK]   To provide an art that can estimate a temperature with means other than a method of directly using a temperature dependence of a physical characteristic of a region whose temperature is to be estimated.

[MEANS OF SOLVING THE PROBLEM] In accordance with whether heat is generated or not, a transistor 300 shows a relatively rapid change, while cooling water CLW shows a relatively mild change. Further, the both settle down to substantially equal temperatures when no heat is generated in the transistor 300. At this time, one of a transistor temperature and a cooling water temperature and the amount of energization of the transistor 300 are used to estimate the temperature of the other one. This method is applied to other temperature estimation, such as estimation of the temperature between a stator coil and a stator iron core of a motor.

[SELECTED DRAWING]   FIG. 3

[Drawings]

FIG. 1

	200	CONTROL SYSTEM
5	210	MAIN ECU
	260	MOTOR CONTROL PART
	270	MASTER CONTROL PART
	220	BRAKE ECU
	230	BATTERY ECU
10	240	ENGINE ECU
	194	BATTERY
	191	DRIVING CIRCUIT
	192	DRIVING CIRCUIT
	150	ENGINE
15		

FIG. 2

	194	BATTERY
	150	ENGINE

20 FIG. 3
AIRFLOW

FIG. 4
CHANGES OF TEMPERATURES OF TRANSISTOR AND COOLING WATER
25 温度   TEMPERATURE
時刻   TIME

FIG. 5
RELATION BETWEEN TEMPERATURE DEVIATION ΔT AND CURRENT
30 VALUE
MOTOR CURRENT VALUE

FIG. 6
AIRFLOW

FIG. 7

CHANGES OF STATOR TEMPERATURES OF FIRST MOTOR MG1 AND
COOLING WATER

5 温度　TEMPERATURE

時刻　TIME

FIG. 8

AIRFLOW

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FIG. 9

CHANGES OF COIL TEMPERATURE AND IRON CORE TEMPERATURE OF
SECOND MOTOR MG2

温度　TEMPERATURE

15 時刻　TIME

FIG. 10

AIRFLOW

20 FIG. 11

CHANGES OF TRANSISTOR TEMPERATURE AND COOLING WATER
TEMPERATURE

温度　TEMPERATURE

時刻　TIME

25

FIG. 12

AIRFLOW

FIG. 13

30 ESTIMATION OF COOLING WATER TEMPERATURE AND OUTSIDE
AMBIENT TEMPERATURE

S1　　INITIALIZE OUTSIDE AMBIENT TEMPERATURE Tair

S2 MEASURE TRANSISTOR TEMPERATURE Ttr WHEN TORQUE OF MOTOR MG1 AND MG2 IS ZERO

S3 ESTIMATE WATER TEMPERATURE Tw FROM ENVELOPE CURVE OF TRANSISTOR TEMPERATURE Ttr WHEN TORQUE IS ZERO (EQUATION (16))

S4 ESTIMATE WATER TEMPERATURE Tw' WHEN TORQUE IS ZERO USING INITIAL VALUE OF OUTSIDE AMBIENT TEMPERATURE Tair (EQUATION (18))

S5 MODIFY OUTSIDE AMBIENT TEMPERATURE SUCH THAT TWO ESTIMATED WATER TEMPERATURE VALUES Tw AND Tw' AGREE WITH EACH OTHER

S6 IS Tair WITHIN NORMAL RANGE?

S7 ESTIMATE WATER TEMPERATURE Tw AT ANY ARBITRARY TIME FROM EQUATION (17) USING MODIFIED OUTSIDE AMBIENT TEMPERATURE Tair

S8 MULFUNCTIONING WARNING

END